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STEAM HEATING DATA,

BY

WM. J. BALDWIN, M. AM. SOC. C. E.,

Mem. Am. Soc. Mech. Engs.

EXPERT

IN

HEATING AND VENTILATION

(*Copyrighted, 1897.*)

PRICE, FIFTY CENTS.

PUBLISHED BY THE AUTHOR,
No. 106 and 108 BEEKMAN STREET,
NEW YORK.

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THE author intends periodically to issue additional concise *data* on the science of heating and ventilation, in small books of this form. This is the first of the series, and to all professional men who receive and preserve the originals intact, there will be issued a bound volume of the completed series upon request.

To architects interested in the science and detail of the subject of heating and ventilation, a prompt answer will be sent by letter to all special enquiries.

The author also desires to say that though his son WM. J. BALDWIN, JR., is interested in the BALDWIN ENGINEERING CO., of New York, that the said company is debarred from bidding on any work for which he is professionally engaged for reasons that are obvious, and that the two businesses are entirely distinct.

STEAM HEATING DATA.

THE object of this little book is to provide ready and approximate preliminary data for the architect or engineer who desires to find the first things necessary for the installation of a steam heating or hot water apparatus.

The rules given are the preliminary ones used in the drawing office of W. J. Baldwin, M. Am. Soc. C. E., designer and expert in heating and ventilation.

They are for heating and ventilating work for which practical and accurate rules are required. The rules are all based on strictly scientific and engineering data, but they are divested of all unnecessary refinement, which for ordinary purposes would only add complication to the task, without getting very much nearer the actual truth.

They are the rules that are required by one when designing a building by which he is

enabled to provide space for boilers, find the horse power, obtain the area of the grate, approximate the coal required, find the size of his chimney, etc., and they are the rules that the ordinary person wants either to commit to memory, or to have at hand in a concise and simple form when wanted.

Explanations will be given when variable factors actually exist. In general, however, I desire to confine myself to the fewest special factors; some of those factors being obtained by multiplying a number of simple factors together.

When a set of plans are placed on my drawing boards, the first consideration by myself or my assistants, is to determine the amount of condensation of steam that has to go on within a building, when that building is properly warmed by the particular method of heating or of heating and ventilation that the owner or the architect may desire to adopt.

The condensation of a building may be found by two different methods. One, a very simple one,

being applied to direct radiation, and one, a little more complex, being used when forced ventilation or large quantities of air by indirect radiation are required. The last method will be considered first.

CONDENSATION.

It may be asked here, "Why the question of condensation is the first consideration," and in reply I will say, that it furnishes us with the first item of data on which to base all our other calculations. For instance, when we find the amount of cooling or condensation that is to take place within a building in the coldest weather, we then know the amount of water that it is necessary to evaporate to do this work. Having the amount of water that is to be evaporated, we can then obtain in any order we please, the size of the boiler necessary to evaporate the water; the amount of coal or other fuel that will evaporate the same water; the size of the grate on which to burn the coal; the size and height of chimney necessary to supply air for combustion;

the size of the radiators necessary to condense the steam ; the size of pipes necessary to convey steam or hot water to the radiators ; and all other attendant data which will develop as we proceed.

CONDITIONS FOR A SCHOOL.

Let us take, for instance, an ordinary primary school building of eight rooms, with say fifty children to a room, (an average condition for primary schools,) and that we have to warm and ventilate this building so as to comply with what is known as the Massachusetts law, which provides that each occupant of the room has to receive a quota of thirty cubic feet of air per minute, which is equivalent to 1,800 cubic feet of air per hour per child. This, therefore, on the basis of the minimum quantity of air allowed by law, and making no allowance for the teacher, will call for the admission of 90,000 cubic feet of air per hour to the school room. Some allowance, however, should be made for the teacher, and also some little factor for safety so as to prevent working too close to the minimum quantity

allowed by law or custom, so that is both reasonable and safe for an engineer or a designer to assume that he should provide at least for the admission and warming of 100,000 cubic feet of fresh air in each hour to each of the eight principal rooms of an ordinary primary school build-

Quantity of Air Required.

ing. This will call for 800,000 cubic feet of air per hour for the class rooms alone, and at least 200.000 cubic feet of air should be provided in addition for ventilation for the other parts of the building. Of course, these quantities are subject to variation in the judgment and experience of the engineer, but for our purpose we will take them as above for the sake of an easy and even example in our calculation. Therefore, an eight room primary school will require about 1,000,000 cubic feet of air per hour for its proper ventilation. Usually, enough warmth can be admitted with this quantity of air to keep the rooms properly and equitably warm, although it is often customary to use additional direct radiation in the halls, etc.

Temperature of Air at Register.

Having now discovered the quantity of air necessary for the building, we have next to consider what its temperature should be as it passes through the registers into the rooms of the building. It is usual to maintain a temperature of 70° Fahr. within a room. It is a common thing to provide in specifications for heating "that the room shall be warmed to 70° Fahr. when the thermometer outside is at zero." If the air passes the registers, however, at 70°, it will not maintain the temperature of the room at 70°, as a certain amount of cooling goes on within the room, due to walls and windows. It is known, however, that should the air pass the registers at a temperature of 100°,(giving the Massachusetts quantity of air) that it is somewhat more than sufficient to maintain the temperature of the room at 70° even when the temperature outside is at zero. It is also known that air passing the registers at 80 or 85° (giving the Massachusetts quantity, say 100,000 cubic feet per hour for the room described) will not main-

tain the temperature of the room at 70°, when the temperature outside drops much below 40°. According to three (3) different theoretical rules (which it is not necessary to mention) assuming average conditions of walls and windows with light on two sides of such a room as we have selected, we have a loss of 27°; 16°, and about 13½° respectively, but my experience has been such that I place it at 30°, and therefore base all my calculations for school work on an increase of 100° above zero as the lowest safe temperature for which I provide means to warm the air.

Air Units.

Having therefore determined that the building requires 1,000,000 cubic feet of fresh air per hour warmed 100°, we have a result of 1,000,000 x 100° degrees Fahr. = 100,000,000, which of course is 100,000,000 cubic feet of air warmed 1°, and which I call 100,000,000 "Air Units;" the air unit being the equivalent of warming one cubic foot of air one degree Fahr. If now we divide these Air Units by an average division of 50, we

have reduced the same to a value of 2,000,000 Heat Units; the Heat Unit being the equivalent of warming one pound of water 1°, while the Air Unit is the equivalent of warming one cubic foot of air 1°.

The Air Unit, however, thus adopted, is an arbitrary unit, and to be correct should be based on warming a cubic measure of air at some *constant* temperature, say at 32° or at zero, or the warming of some *constant* weight of air, irrespective of its temperature. For our purpose, however, the divisor 50 is approximately correct, and is obtained thus:—

One pound of air at 32° Fahr. under a pressure of an atmosphere of 29.9 inches of mercury, will occupy a space of 12.38 cubic feet, and its specific heat is .2379; the specific heat of water being unity. In other words, a pound of water requires 4.2 times as much heat to increase its temperature one degree Fahr. as a pound of dry air does; so that the warming of 4.2 pounds of air 1° is the equivalent of cooling one pound of water 1°. We have thus, one pound of air at 32° Fahr., oc-

cupying a space of 12.38 cubic feet x 4.2, which equals 52 cubic feet, or the bulk of air at a temperature of 32° that can be warmed by 1 Heat Unit. This, as will be noted, is for air at 32°. Now, if the air instead of being 32° is zero, following the same method of reasoning as we have above, its bulk will be 48.6 cubic feet for each Heat Unit, and at a temperature of 14° above, its bulk is 50 cubic feet; while at 70° Fahr. it will be 56.2 cubic feet. This therefore gives the range of bulk for air between zero, the coldest outside temperature on which calculations are usually made, to 70°, the temperature of the room, and shows why 50 can be taken as a proper divisor without appreciable error.

British Heat Units.

We have found above, therefore, that for every million cubic feet of air admitted to the building in an hour (or any time) and warmed 100°, that we will have to furnish steam equal to 2,000,000 British Heat Units in the same time. To warm this quantity of air the equivalent of 2,000,000

Heat Units, we will have to cool a quantity of steam equal to 2,000,000 Heat Units, and here again another average divisor of 1,000 may be used without appreciable error, by which we obtain the amount of steam necessary to be condensed (or to be evaporated), and the answer will be in pounds weight of steam or water; which, in the instance we have cited is the equivalent of 2,000 pounds weight of steam condensed or 2,000 pounds of water evaporated to steam in a boiler.

Heat Units in One Pound of Steam.

Let us now see how this divisor of 1,000 is obtained. If we evaporate one pound of water from a temperature of 212° (under our ordinary pressure of atmosphere) it requires 965 Heat Units to accomplish the evaporation, and to turn the water into steam at a pressure just above the atmosphere (according to Regnault's tables,) and if we look at any of the tables of the heat of steam, we will find that the *latent* heat of vaporization decreases with an increase of pressure, but that the *sensible* heat increases, and that the

sum of the sensible and latent heat of steam above 212° forms a nearly constant quantity, increasing slightly with the increase of pressure, so that at ten pounds pressure it is the equivalent of 974 Heat Units, and at forty pounds pressure it is the equivalent of 989 Heat Units, while at one hundred pounds pressure it is the equivalent of 1,004 Heat Units. I follow this line of reasoning on the assumption that we always cool the water in the return pipes to 212°, or something below it.

In low pressure apparatus it cools considerable below 212°, so that it is only necessary to cool it to 178° to extract the whole 1,000 Heat Units from it. Therefore the divisor of 1,000 (Heat Units,) is obtained by cooling one pound weight of steam from say one pound pressure above atmosphere to water at a temperature of about 178° in the return pipes, and which would become but 1,004 heat units if we cool the steam from one hundred pounds pressure to a temperature of 216° in the return pipes, all of which are good average conditions. Therefore, the divisor of

1,000 is not empirical, but founded on science and practice.

If we therefore divide our 2,000,000 Heat Units by our constant of 1,000, (the Heat Units in a pound weight of steam,) we find that we have to condense just 2,000 pounds weight of steam at any ordinary pressure, to supply our 2,000,000 Heat Units, necessary to warm the 1,000,000 cubic feet of air 100° Fahr.

Horse Power.

Having now discovered that we require to evaporate 2,000 pounds of water or condense 2,000 pounds of steam, and we divide this 2,000 by 30, and have the result in centennial horse-power; which is equivalent to 66.6 horse-power. This, therefore, gives us the boiler capacity we have been looking for.

Coal.

After having found our boiler it becomes necessary to approximate the amount of coal that we may have to burn, so that we may be able to estimate our expense and also arrive at the size

of our grate. Having the amount of water that it is necessary to evaporate, say 2,000 pounds, a simple method indeed is to divide the weight of water in pounds by another constant divisor of ten (10) and the result is the weight of good coal that will be burned to evaporate that quantity of water. This ten (10) is also a slightly variable quantity, and will vary from *eight* to *eleven* with different types of boilers. I use the *ten* for all ordinary rough calculations, although some say nine may be nearer the actual conditions of common practice; ten being good practice. Therefore, if we divide the 2,000 pounds of water by *ten*, it shows that we have to burn about two hundred pounds of coal per hour to warm 1,000,000 cubic feet of air 100° in the same time.

GRATE.

Having found the amount of coal to be burned, it then becomes necessary to establish the size grate necessary to burn this coal. It is said that in burning coal under large boilers when a

fireman is in attendance, that the greatest results in economy have been obtained when the coal has been burned at the rate of about nine pounds per hour per square foot of grate. This diction, however, is open to question. For a low pressure apparatus in house work or school work in the care of janitors, and any apparatus that is made automatic and that will have to run for long periods without attention, four to five pounds of coal per hour per square foot of grate is ordinary practice ; hence the large proportion of grate in small boilers. Again, with high pressure power boilers, twelve to one, and even higher is not considered bad practice. This question, therefore, admits of great latitude, but for boilers for all ordinary large buildings, (power boilers,) ten to one and twelve to one, becomes a good rule. In other words, divide the amount of coal by ten or twelve, and you have the square feet of grate necessary and proper to burn it under average conditions of practice.

The ten to one would give us twenty square feet of grate for a sixty-seven horse-power boiler,

which is rather a larger grate than a sixty-seven horse-power horizontal boiler would require, and where ten may be a good ordinary divisor, twelve will probably be nearer the ordinary and every-day practice, when circumscribed by local conditions.

CHIMNEY.

The next question to consider is that of the chimney necessary to burn the amount of coal required. The chimney, when accurate data is required, should be calculated by the amount of coal to be burned and the height of the chimney, but this is a complex question in itself, and we have no room for it just here.

A common old rule for proportioning the size of the chimney for the grate, is to take one-eighth of the grate area, and call it "chimney." Nothing was said about the height of the chimney, and at the best this was but a crude approximation, and often disappointing with short chimney, although at the present time in New York with high buildings over one hundred feet, it is a safe rule to follow.

RECAPITULATION.

We can now recapitulate the whole of the foregoing matter in the following simple manner by an arithmetical example, thus :

(1) 1,000,000 cubic ft. air passing through building in an hour.
$\times$ 100° Fahr. air is warmed (0. to 100. F.)

50)100,000,000 Air Units.

1000)2,000,000 Heat Units required in an hour.

10)2,000 lbs. water to be evaporated in boiler or steam condensed in apparatus per hour.

12)200 lbs. coal required per hour.

8)16.6 sq. ft. of grate (minimum.)

2.075 sq. ft., size of chimney 100 ft. high.

The above speaks for itself.

If now we desire to find only the horse-power

of the boiler, we divide the number of pounds of water to be evaporated per hour by *thirty*, thus :

(2) 30)2,000 lbs.

———

66.6 horse-power.

Boiler Surface.

If again we desire to know the square feet of surface that such a boiler should have to furnish 66.6 horse-power, you may take "the boiler maker's rule" of allowing fifteen square feet per horse-power, which is the usual amount provided in horizontal multitubular boilers, and we have the following simple example :—

(3) 66.6 horse-power of boiler.

15 sq. ft. per horse-power.

———

999 sq. ft. of surface in boiler.

which is practically 1,000 square feet of surface for such a boiler.

The foregoing simple data, therefore, establishes the amount of air necessary for the school ; the temperature to which provision should be

made for warming the air; the total (British) units of heat necessary to warm the air; the amount of water necessary to be made into steam (or steam to be condensed into water) necessary to supply the foregoing units of heat; the amount of coal required to be burned per hour; the reasonable size of the grate on which to burn the coal; the size of the chimney necessary for combustion; the power of the boiler in nominal horse-power, and the number of square feet of fire and flue surface in the boiler.

The above is for indirect work for school buildings, hospitals, etc., and in the following I will endeavor to consider the question of similar calculations when based on direct radiation without systematic ventilation.

Direct Radiation.

Having determined the amount of direct radiating surface necessary for warming a room or for a building, it becomes necessary to know how to obtain the boiler, etc., for the same. The radiating surface for the building may be deter-

mined by any of the ordinary rules of practice, a very good one for which is given in my work on *Steam Heating*, published by John Wiley & Sons, or in my work on *Hot Water, Heating & Fitting*, published by the *Engineering Record*, both of which books go deeply into detail on the entire subjects of warming.

Having found or established the radiating surface, therefore, we can proceed as follows :

Multiply the heating surface in square feet, either by the number of pounds of steam that it is known the particular type of radiator will condense in an hour, or by the number of *heat units* when that is known, and which is pretty well established for different types of radiators and coils.

Horizontal coils of plain pipe, well distributed, have the highest efficiency as direct heaters. Then come the simple types of vertical radiators, when not of too great a height. The higher a radiator is, the lower its efficiency per square foot of surface, and thirty-six or thirty-eight inches has been established as a fair limit of

height, so as to prevent an unnecessary waste of floor room, with reasonable economy in iron and in cost.

CONDENSATION.

Without going into the matter in detail, therefore, it is only necessary for me to say that in horizontal one inch pipe in wall coils, the condensation per square foot of surface is found to be about .3 of a pound of water per square foot per hour for low pressures (one or two pounds pressure of steam,) and that it decreases to about .25 of a pound of water per square foot per hour for the average types of radiators.

Taking the value, therefore, of a pound of steam at 1,000 Heat Units, we have 300 Heat Units per square foot of surface for coils, which in some cases, run a little over this, and 250 Heat Units per square foot of surface for average radiators. The condensation, however, will vary and increase with an increase of pressure of steam, and numerous experiments have demonstrated that the condensation in different types of

radiators and coils can be reduced to the equivalent of 1.66 Heat Units per degree difference, between the temperature of the air of the room and the temperature of the steam, per square foot of heating surface, for the poorer types, to about 2.25 Heat Units for the more efficient direct radiators and coils.

Assuming, therefore, that we have a radiator of 100 square feet in a room at 70°, with a pres- of steam at one pound, or 215°, we have a difference of temperature between the steam and the air of the room of 145°, and should the type of radiators or coils be unknown to us, other than that the building is to be warmed by direct radiation, it is reasonable to assume that we may average the loss of heat per square foot of surface per degree difference of temperature at two Heat Units, which is my usual practice (unless I know exactly what type the radiators are to be,) and which gives us a total loss of heat of 290 Heat Units per square foot of surface, for a radiator of 100 square feet, therefore the loss of heat is equivalent to 29,000 Heat Units, or say the condensa-

tion of twenty-nine pound of steam, while for a building of 1,000 square feet of surface, it will amount to 290,000 Heat Units, and so on.

For the sake of easy calculation, therefore, we will assume that we have a building with 10,000 square feet of radiation, and desire to find the boiler, etc., we may proceed as follows:

(4) 10,000 sq. ft. of radiation in building.
290 Heat Units lost per sq. ft. per hour

1,000)2,900,000 Total Heat Units.

10)2,900 lbs. Water to be evaporated or steam to be condensed per hour

12)290 lbs. coal required per hour.

8)24.16 sq. ft. of grate.

3.2 Area of chimney in sq. ft. 100 feet high.

The horse power of the boiler and the surface in square feet can be found as shown before in examples (2) and (3).

EMPIRICAL RULES.

Simple empirical rules based on the foregoing are :—

HEAT UNITS.

(1.) Having the cubic feet of air to pass through a building in an hour, and warmed 100° Fahr., multiply it by two (2,) and the answer is in *Heat Units.*

POUNDS WEIGHT OF STEAM.

(2.) Having the cubic feet of air to pass through a building in an hour, and warmed 100° Fahr., desiring the weight of steam required to warm same, divide by 500, and the answer is in ***pounds weight of steam.***

COAL REQUIRED

(3.) Having the cubic feet of air to pass through a building in an hour, and warmed 100° Fahr., and requiring the amount of coal to be burned per hour, divide by 5,000, and the answer is in ***pounds weight of coal.***

Size of Grate.

(4.) Having the cubic feet of air to pass through a building in an hour, and warmed 100° Fahr., and requiring the grate area, divide by 60,000, and the answer is in *square feet of grate.*

Size of Chimney.

(5.) Having the cubic feet of air to pass through a building in an hour, and warmed 100° Fahr., and requiring the chimney 100 feet high, divide by 500,000, and the answer is in *square feet of cross sectional area.*

Required Horse Power.

(6.) Having the cubic feet of air to pass through a building in an hour, and warmed 100° Fahr., and requiring the horse power of the boiler, divide by 15,000, and the answer is in *horse power.*

Boiler Surface.

(7.) Having the cubic feet of air to pass through a building in an hour, and warmed 100° Fahr., and require the number of square feet of heating surface in boiler, divide by 1,000, and the answer is in *square feet.*

Wm. J. Baldwin.

CARD BY THE AUTHOR.

THE author offers his services as an Expert and Designer of heating, cooling and ventilating plants and general engineering.

He has had twenty-eight years experience, both practical and theoretical, with a thorough knowledge of all the minutia of detail of construction. His experience enables him to assure economy, both in design and maintenance.

Below are a few of the buildings for which he has furnished plans, specifications, etc.

Vanderbilt Memorial Hall (Yale College,) New Haven, Conn.
The (new) College of Physicians and Surgeons of the City of New York.
The Vanderbilt Clinic, New York.
The Sloane Maternity Hospital, New York.
Lawyers' Title Insurance Co.'s Office Building, New York.
Hanover Fire Insurance Co.'s Office Building, New York.
The Metropolitan Telephone and Telegraph Co.'s Office Building.
Mechanics Bank Office Building, Brooklyn.
Exchange Office Building, New Haven, Conn.
New Laboratory, College Physicians and Surgeons, N. Y.
Wm. J. Syms Operating Theatre, (Roosevelt Hospital,) N. Y.
Columbia College Medical Department (easterly and westerly extensions.)
American Theatre, New York.
Manhattan Co.'s and Merchants' Bank Office Building.
The Importers' & Traders' Bank.
U. S. Army Mess Hall, David's Island, N. Y. Harbor.
U. S. Army Barracks, David's Island, N. Y. Harbor.
George Street Public School, New Haven, Conn.
Norton Street Public School, New Haven, Conn.
Dwight School, New Haven, Conn.
Lemair Schwartz, Factory Building, N. Y.
Hundreds of other large buildings and residences throughout the United States.

TERMS FURNISHED ON APPLICATION.

THE Author is the pioneer writer in America on the subject of Steam Heating.

His work "BALDWIN on HEATING," has reached the 14th edition. Price $2.50.

His work "HOT WATER HEATING AND FITTING" is in the 3rd edition. Price, $4.00.

They are the standard American works of reference on these subjects.

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